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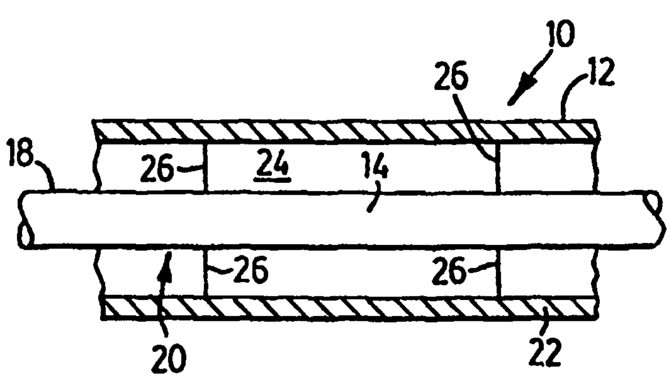
(54) Title: FREEZE PROTECTION APPARATUS FOR FLUID TRANSPORT PASSAGES

(57) Abstract

An elongated conduit (12) for conveying or containing liquid is provided comprising a flexible membrane (18), wherein the membrane (18) is disposed in substantially adjacent relationship with a compressible elastomeric material (14), the compressible elastomeric material (14) being supported by a permeable rigid support member (26). The membrane surface, adjacent to a second surface or the compressible elastomeric material, has a surface area exceeding the greater of (i) the area of the second surface when no liquid is in the conduit, and (ii) when the compressible elastomeric material is compressed due to freeze expansion.



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# FREEZE PROTECTION APPARATUS FOR FLUID TRANSPORT PASSAGES

## Field of Invention

The present invention pertains to the field of freeze protection in fluid handling apparatus and, more particularly, to such freeze protection devices applied to solar thermal collectors and conduits.

## Background of the Invention

In colder climates where fluid carrying apparatus may be subjected to sub-zero temperatures, reliability of such equipment may be compromised by freeze damage. Under cold temperature conditions, working fluids comprised of aqueous liquids may freeze and, consequently, expand. If the working fluid is confined within rigid fluid passage walls, its expansion during freezing will be resisted. As a result, when freezing occurs, pressure increases within the fluid passage, which, depending on the rigidity, could lead to failure and rupture of the structure of the fluid passage after one or more freezing cycles.

Such reliability concerns exist with solar thermal collectors. The conversion of solar radiation to heat for building applications is achieved by circulating a working fluid, typically an aqueous liquid, through an arrangement of channels or like conduits or tubes that are typically in contact with a highly thermally conductive sheet whose selectively coated surface is exposed to the incident solar radiation. The heated fluid is then distributed to thermal storage and to building applications, such as space heating and domestic hot water heating. The actual solar radiation conversion device is a solar thermal collector.

Presently, three types of solar thermal collectors exist in building applications that embody the combination of a selectively coated sheet, or absorber sheet, and fluid-carrying channels or tubes. They are the flat plate collector, the heat pipe collector, and the evacuated tubular collector. Each type of collector can be divided into two functional zones: the collector absorber unit and the absorber unit encasement. The collector absorber unit consists of the assembly of the fluid carrying apparatus and the absorber sheet. Such working fluid carrying apparatus includes fluid passages defined by rigid walls for facilitating the transportation of the fluid through the collector absorber unit.

The prior art features several attempts to improve the ability of the collector absorber unit to endure conditions of fluid freezing for over 20 years of operation. Several means of dealing with the freezing of the working fluid have been proposed over the years by the solar industry, and by other fluid handling sectors as well.

In one method, water is removed from zones in the collecting apparatus where freezing conditions are expected. This strategy has been incorporated into the operation of drain-back and drain-down solar thermal systems. A control system signal initiates the removal of the fluid from the fluid passage that is exposed to the freezing conditions. In this case, reliability of the control system becomes critical. If the working fluid fails to be removed, then nothing protects the fluid carrying apparatus from freezing damage.

In accordance with another method, fluids with freezing points that are lower than temperatures expected during operation are used. In general, such fluids are expensive, offer poor thermal properties, and involve high fluid handling costs. In all cases, they fail to provide significant gains in cost-effectiveness and do not justify their contribution to the prevention of freezing. Prime examples of this method are the circulation of silicone oils or air in the solar thermal collector loop. Silicon oils are of high cost. They have thermal capacities which are lower than water. To match the thermal performance of the water, silicone oils must be circulated at high mass flows that cannot be justified because of the resultant increase in fluid handling costs, such as pump costs. Moreover, silicone oil is challenging to contain, thus necessitating additional cost-generating measures. Air has a very low thermal capacity and low thermal conductivity and therefore, is only appropriate for space heating systems, which limits its scope of application.

A further means of preventing freeze damage is to inject chemical additives to lower the freezing point of the working fluid. The chemical stability of such mixtures is questionable over long operating periods, thus adding maintenance costs and creating new reliability concerns. Moreover, this method must conform with local regulations relating to domestic water contamination, thus incurring additional costs. A conventional application of this method in solar thermal systems is the addition of propylene glycol to water. Historically, this mixture has been known to break down at collector stagnation temperatures while in the presence of oxygen. Without proper maintenance the propylene glycol mixture forms clumps and becomes corrosive over time, which results in a loss of performance and capacity to protect from freezing.

Another means disclosed in the prior art is the use of a flexible and resilient insert inside the fluid channels of the solar thermal collector. Examples of such inserts are disclosed in U.S. Patent

Nos. 5,579,828; 4,227,512; 4,321,908; and 3,989,032. The insert can accommodate the expansion that the working fluid experiences upon freezing and thus protects the fluid carrying apparatus from rupturing. Although this design is very effective in freeze protection, it creates additional manufacturing costs (e.g. outfitting the fluid carrying apparatus with the insert). The operation of the insert is also plagued with reliability and durability concerns. Typically, the insert consists of a skin or sheath filled with a gas at a pressure higher than the working fluid pressure. The sheath or skin may be comprised of thin metal sheets, plastics, or elastomeric tubes. For a collector life that is expected to extend beyond the 20 year mark, flexible metallic inserts are unreliable because they will typically fail as a result of material fatigue, thermal aging, corrosion, or a combination thereof. Increasing the metal thickness to delay metal deterioration, due to corrosion or thermal aging, only increases the costs and curtails flexibility and capacity to accommodate the expansion of a freezing fluid. Over similar operating periods, plastic thin-walled inserts may get saturated with the working fluid since plastics are permeable to most fluids typically used in heat transfer applications. This renders the insert ineffective for freeze protection. In the case of solar thermal collectors, increasing the skin thickness to decrease permeability will unjustifiably increase the material costs since expensive high temperature plastics, such as Teflon™, are required to withstand stagnation conditions (which can exceed 200°C). Similar material costs and saturation issues apply to elastomeric inserts. Furthermore, thin walled pressurized designs, whether made of metal or plastic, are not robust because they are vulnerable to skin puncture, which subsequently renders the insert ineffective upon depressurization.

Other attempts in dealing with the freeze problem have included using conduits made with flexible and resilient walls to accommodate fluid expansion upon freezing, such as that disclosed in U.S. Patent 4,299,200. The walls of such conduits are made of plastics, elastomers, or metals, and therefore are similar to the materials used within the above-described inserts. As a result, this particular solution does not escape the same issues of robustness, material costs, metal fatigue, and corrosion which arise in association with the use of the insert. In addition, the use of plastics or elastomers as channel walls may impede performance of solar thermal collectors, or any heat exchanger application where this solution is incorporated because of the low thermal conductivity characteristics associated with such materials.

In yet another means of freeze protection, a controlled heat source is employed in the regions where freezing of the working fluid is anticipated. As in the first-mentioned prior art attempt at dealing with this problem, the reliability issue is not solved, but merely shifted to the operation and

control of the heat source. Further, with respect to solar thermal applications, this solution adds new components and thus additional costs.

**Summary of Invention**

The present invention discloses an apparatus for freeze protection of conduits used for the transportation of aqueous liquids.

In one broad aspect, the present invention provides an elongated conduit for conveying or containing aqueous liquid, defining a liquid passage, comprising a first portion and a second portion, the first portion being a rigid wall and the second portion being a substantially liquid impermeable flexible membrane. The membrane is disposed in substantially adjacent relationship with a compressible elastomeric material, the compressible elastomeric material being supported by a rigid support member having perforations for external drainage of liquid. The conduit can form part of a solar thermal collector. Further, the compressible elastomeric material is selected from the group consisting of foamed butyl rubber, foamed neoprene, silicone foam, silicone sponge rubber and urethane foam.

In another aspect, the present invention provides an elongated conduit for conveying or containing aqueous liquid, defining a liquid passage, comprising a first portion and a second portion, the first portion being a rigid wall and the second portion being a substantially liquid impermeable flexible membrane, the rigid wall being attached to the flexible membrane wherein together they form an outer perimeter of the liquid passage. The membrane is disposed in substantially adjacent relationship with a compressible elastomeric material. The membrane has a first surface characterized by a first surface area, and the compressible elastomeric material has a second surface characterized by a second surface area. The first surface is in substantially adjacent relationship with the second surface. The first surface area exceeds the greater of the second surface area, when the liquid passage contains no liquid and the compressible elastomeric material is in an uncompressed state or in a precompressed state, and the second surface area when the compressible elastomeric material is in its compressed state as a result of freeze expansion of the aqueous liquid.

In another aspect, the present invention provides a conduit for conveying or containing aqueous liquids, comprising a substantially liquid impermeable flexible membrane for defining a liquid passage. The membrane is disposed in substantially adjacent relationship with a compressible elastomeric material, the compressible elastomeric material being supported by a permeable rigid support member. The rigid support member can include perforation for external drainage of liquid.

In yet another aspect, the present invention provides a conduit for conveying or containing aqueous liquids, comprising a substantially liquid impermeable flexible membrane for defining a liquid passage. The membrane is disposed in substantially adjacent relationship with a compressible elastomeric material. The membrane has a first surface characterized by a first surface area, and the compressible elastomeric material has a second surface characterized by a second surface area, the first surface being in substantially adjacent relationship with the second surface. The first surface area exceeds the greater of (i) the second surface area, when the liquid passage contains no liquid and the compressible elastomeric material is in an uncompressed state or in a precompressed state, and (ii) the second surface area when the compressible elastomeric material is in its compressed state as a result of freeze expansion of the aqueous liquid.

In yet a further aspect, the present invention provides a conduit for conveying or containing aqueous liquids comprising a substantially liquid impermeable flexible membrane for defining a liquid passage. The membrane is disposed in substantially adjacent relationship with a compressible elastomeric material. The membrane includes a first portion and a second portion. An exterior of the first portion is disposed in substantially adjacent relationship with a first rigid structural support member and an exterior of the second portion is disposed in substantially adjacent relationship with a compressible elastomeric material.

In yet a further aspect, the present invention provides a conduit for conveying or containing aqueous liquids comprising a substantially liquid impermeable flexible membrane for defining a liquid passage. The membrane is disposed in substantially adjacent relationship with a compressible elastomeric material. The membrane and the compressible elastomeric material are supported by a rigid support member. The rigid support member is formed from a single sheet having a first edge and a second edge joined by a width. The single sheet is bent proximate the first edge to form a hem and a flap. The first edge is rolled over itself to form an interior rolled-over surface portion. The single sheet is further provided with a first bend along the width. The membrane and the compressible elastomeric material are substantially contained by the interior rolled-over surface portion. The first bend is disposed between the hem and the second edge. The flap is disposed within the first bend to form a lock. The first bend can join a first portion of the width to a second portion of the width, the first portion and the second portion extending from the first bend, the flap being inserted and pressed between the first portion and the second portion whereby the flap lockingly engages the first bend. The hem can contact a surface of the width to form a seam. The compressible elastomeric material can be disposed between the seam and the membrane. The lock

can be liquid permeable. The single sheet can be further provided with a second bend disposed between the first bend and the second edge, the second bend joining a third portion of the width to a fourth portion of the width, the third portion and the fourth portion extending from the second bend, the fourth portion forming an absorber plate in a solar thermal collector.

In a further aspect, the present invention provides a method of constructing a freeze protected conduit for conveying or containing aqueous liquids comprising the steps of (i) bending a single sheet having a first edge and a second edge joined by a width to form a hem and a flap proximate the first edge, (ii) rolling the first edge over itself to form an interior rolled-over surface portion, (iii) bending the sheet at a first point along the width between the hem and the second edge to form a first bend, the first bend joining a first width portion and a second width portion, the first width portion and the second width portion extending from the first bend, (iv) inlaying a flexible conduit and compressible elastomeric material against the interior rolled-over surface portion for effecting containment and support of the flexible conduit and the elastomeric material, and (v) pressing the flap between the first width portion and the second width portion to form a lock. Step (iv) must occur before step (v) and after step (ii), and wherein step (iii) must occur before step (v). The hem contacts a second point along the width of the sheet during step (ii).

In yet another aspect, the present invention provides a freeze protected conduit for conveying or containing aqueous liquids, defining a liquid passage, comprising a substantially liquid impermeable membrane disposed in substantially adjacent relationship with a compressible elastomeric material, wherein the membrane comprises silicone rubber. The membrane has a thickness within the range of about 0.007 inches to about 0.020 inches. The conduit is used in heat transfer applications.

**Brief Description of the Drawings**

The invention will be better understood and objects other than those set forth above will become apparent when consideration is given to the following detailed description thereof. Such description makes reference to the annexed drawings wherein:

**Figure 1** is a side elevation sectional view of one embodiment of the present invention;
**Figure 2** is an end elevation sectional view of the embodiment illustrated in Figure 1;
**Figure 3** is an end elevation sectional view of a second embodiment of the present invention;

**Figure 4** is an end elevation sectional view of another example of the second embodiment of the present invention;

**Figure 5** is an end elevation sectional view of a third embodiment of the present invention;

**Figure 6** is an end elevation sectional view of another example of the third embodiment of the present invention;

**Figure 7** is an end elevation view of another example of the second embodiment of the present invention where compressible elastomeric material is in its uncompressed or precompressed state;

**Figure 8** is an end elevation view of the embodiment illustrated in Figure 7, showing the compressible elastomeric material having adopted a concave profile after freeze expansion of liquid;

**Figure 9** is an end elevation view of a fourth embodiment of the present invention;

**Figure 10** is an end elevation view of a fifth embodiment of the present invention;

**Figure 11** is an end elevation view of a partial construction of the embodiment illustrated in Figure 10, showing such embodiment in the first stage of construction;

**Figure 12** is an end elevation view of a partial construction of the embodiment illustrated in Figure 10, showing such embodiment in the second stage of construction;

**Figure 13** is an end elevation view of a partial construction of the embodiment illustrated in Figure 10, showing such embodiment in the third stage of construction;

**Figure 14** is an end elevation view of a partial construction of the embodiment illustrated in Figure 10, showing such embodiment in the fourth stage of construction;

**Figure 15** is a pictorial flowsheet of a solar thermal collector process;

**Figure 16** is a side sectional view of a further embodiment of the present invention, as applied to a typical fluid passage within the solar thermal collector of Figure 15;

**Figure 17** is a side sectional view of a further embodiment of the present invention, as applied to a fluid passage between the absorber units within the solar thermal collector of Figure 15;

**Figure 18** is a side sectional view of the present invention as applied to the supply and return lines of the solar thermal collector of Figure 15;

**Figure 19** is a front sectional view of the application of the present invention illustrated in Figure 18, taken along line A-A thereof; and

**Figure 20** is a front sectional view of the application of the present invention illustrated in Figure 18, taken along line B-B thereof.

**Detailed Description of the Preferred Embodiment**

Referring to Figures 1 and 2, a freeze protected conduit **10** of the present invention, having a length, comprises an elongated conduit **12** for conveying or containing aqueous liquid, and an elongated, compressible elastomeric material **14**, less rigid than conduit **12**, disposed within conduit **12** along the above-mentioned length.

The compressible elastomeric material, such as typified by numeral **14** in Figures 1 and 2, is comprised of resilient, compressible elastomeric material that has an elasticity that provides a stress-strain relationship which will keep stresses in the conduit **12** at levels below what would otherwise cause failure of conduit **12**. The compressible elastomeric material **14** also has a shape memory which will provide freeze protection for the number of compression cycles anticipated over the operating life of the conduit **12**. Examples of compressible elastomeric material **14** include silicone foam, foamed butyl rubber, foamed neoprene, silicone sponge rubber, urethane foam, foamed EPDM, and other elastomers.

Preferably, the compressible elastomeric material **14** is fully sealed on all its sides and ends by a substantially liquid impermeable membrane **18** to form an insert **20** which is disposed inside of conduit **12**. In this respect, membrane **18** behaves like a flexible wall which, along with rigid wall **22** of conduit **12**, define an annular fluid passage **24**.

Preferably, insert **20** is disposed along the axis of conduit **12**, particularly where conduit **12** is used in heat transfer applications. Because the insert **20** is centrally located, it does not interfere with heat transfer between the conduit wall and the aqueous liquid in fluid passage **24** and is, therefore, particularly suitable for use in heat transfer applications, such as a solar thermal collector or photovoltaic cells. Referring particularly to Figure 2, insert **20** is retained in its generally central position within conduit **12** by the use of straps, splines or other supports **26** which supports insert **20** along its length. Preferably, such supports **26** will not be continuous but instead will be intermittent or spaced along the length of insert **20** so as to minimize interference with the flow or movement of liquid within conduit **12**. In one embodiment, the present invention may be provided with a plurality of splines **26** extending radially from insert **20** for biasing against the rigid wall **22** of conduit **12**. Alternatively, splines **26** may extend radially inward from rigid wall **22** of conduit

**12** for biasing against insert **20**. In any event, use of the insert **20** can also be extended to any fluid handling apparatus that requires protection from fluid freezing damage.

Substantially liquid impermeable membrane, such as typified by numeral **18** in Figures 1 and 2, is generally constructed of a material that does not raise any corrosion, strength, chemical stability or thermal stability issues when operating in its working environment over the life of the apparatus. A choice for membrane material is a thin metal foil coated with a protective layer such as a plastic film. Another preferred choice is a thin, flexible, plastic membrane. Examples of plastic membrane materials include thermoplastics and elastomers. Polyesters, such as Kaladex™, and fluoropolymers, such as Teflon™ are choices of thermoplastics for a solar thermal collector environment. The preferred choice for membrane material is an elastomer, of which silicone rubber is a preferred example in solar thermal collector applications. The elastic nature of elastomers allows elastomeric membranes to possess thicker walls than membranes made of other material, such as thermoplastics. This greatly improves membrane robustness, and as a result improves the reliability of the membrane as a fluid containment component. Preferably, thickness of membranes used in the various embodiments of the present invention is within the range of about 0.007 inches to about 0.020 inches for elastomers, and 0.002 inches to 0.005 inches for thermoplastics, for optimal combination of heat transfer and reliable fluid containment.

When aqueous liquid in conduit **12** is subjected to freezing conditions, it will solidify and expand. As a result, compressible elastomeric material **14** deforms inwardly and becomes compressed to accommodate volumetric expansion of the freezing liquid in conduit **12** by effectively increasing the size of fluid passage **24**. The compressible elastomeric material **14** is of such elasticity that it provides fluid passage **24** with the ability to increase its size. Without this ability for fluid passage **24** to increase in size, the freezing of liquid and consequent expansion (hereinafter also referred to as "freeze expansion") would create tensile such stresses in conduit **12**, that could cause rupture of conduit **12**. Upon thawing of the working fluid, the resilience of the compressible elastomeric material **14** enables it to spring back to its original shape. The compressible elastomeric material **14** has the additional advantage that it will not immediately lose its resiliency if the fluid permeates through membrane **18**. In other words, if membrane **18** is punctured, the compressible elastomeric material **14** will not immediately lose its ability to assist in freeze protection.

In another embodiment of the present invention, particular examples of which are illustrated in Figures 3 and 4, an elongated conduit **28a, 28b** is provided comprising a rigid wall **30a, 30b** and a substantially flexible liquid impermeable membrane **32a, 32b**, wherein rigid wall **30a, 30b** is

connected to membrane **32a, 32b** to form a fluid tight seal and define a fluid passage **34a, 34b**. Membrane **32a, 32b** is supported by compressible elastomeric material **36a, 36b**, disposed substantially adjacent to the exterior surface **35a, 35b** of membrane **32a, 32b**. Supporting compressible elastomeric material **36a, 36b** is support member **38a, 38b**, wherein support member **38a, 38b** is of greater rigidity than compressible elastomeric material **36a, 36b**. Preferably, the compressible elastomeric material **36a, 36b** is fully contained on all its sides and ends by support member **38a, 38b** and membrane **32a, 32b**.

In yet a further embodiment, examples of which are illustrated in Figures 5 and 6, a flexible conduit **40a, 40b**, having a length, and defining a fluid passage **42a, 42b**, is disposed within rigid structural support member **44a, 44b**. Also disposed within rigid structural support member **44a, 44b**, and in substantially adjacent relationship with exterior wall **41a, 41b** of flexible conduit **40a, 40b** is compressible elastomeric material **46a, 46b**.

Flexible conduit **40a, 40b** comprises a substantially liquid impermeable membrane **48a, 48b**, which functions as a flexible wall of conduit **40a, 40b**. Membrane **48a, 48b** is disposed in substantially adjacent communication with either of rigid structural support member **44a, 44b** or compressible elastomeric material **46a, 46b**, thereby receiving structural support from either or both of member **44a, 44b** and material **46a, 46b**. Preferably, flexible conduit **40a, 40b** and compressible elastomeric material **46b, 46b** are fully contained by rigid structural member **44a, 44b**.

To further protect any of membranes **18, 32a, 32b,** or **48a, 48b** in the corresponding embodiments illustrated in Figures 1, 2, 3, 4, 5 or 6 from tensile forces caused by freeze expansion, the surface area of the membrane **18 (32a, 32b, 48a, 48b)** is preferably of a sufficient size. In this respect, depending on the geometry of the compressible elastomeric material **14 (36a, 36b, 46a, 46b)**, the size of the surface area of a first surface of the membrane **18 (32a, 32b, 48a, 48b)** in substantially adjacent relationship with a second surface compressible elastomeric material **14 (36a, 36b, 46a, 46b)**, preferably, exceeds the greater of:

(i) the surface area of the second surface of compressible elastomeric material **14 (36a, 36b, 46a, 46b)** when the liquid passage contains no liquid and compressible elastomeric material **14 (36a, 36b, 46a, 46b)** is;

a) in an uncompressed state, or

b) in a precompressed state and

(ii) the surface area of the second surface of compressible elastomeric material **14** (**36a, 36b, 46a, 46b**), when compressible elastomeric material **14** (**36a, 36b, 46a, 46b**) is in its compressed state as a result of freeze expansion.

To further illustrate how geometry of compressible elastomeric material **14** (**36a, 36b, 46a, 46b**) dictates the preferred choice of membrane **18** (**32a, 32b, 48a, 48b**) surface area, an embodiment of the present invention depicted in Figure 4 shows compressible elastomeric material **36b** of a geometry wherein that part of its surface in substantially adjacent relationship to membrane **32b** (hereinafter, "the operative surface area") is of a convex profile relative to membrane **32b**. In this case, as compressible elastomeric material **36b** deforms and compresses to facilitate freeze expansion in fluid passage **34b**, the operative surface area becomes smaller. Therefore, in this case, to assist in preventing membrane **32b** from experiencing tensile forces, surface area of membrane **32b** should, preferably, exceed the operative surface area of compressible elastomeric material **36b** when in its uncompressed state (ie. the condition where such operative surface area is at its largest point).

In other geometries, an example of which is illustrated in Figure 3, the operative surface area of compressible elastomeric material **36a** is largest when the compressible elastomeric material **36a** is in its compressed state. In such cases, the surface area of membrane **32a** should, preferably exceed that of the operative surface area of the compressible elastomeric material **36a** when in its compressed state as a result of freeze expansion.

As a further illustrative example, an embodiment of the present invention depicted in Figure 7 shows compressible elastomeric material **36c** of a geometry wherein its operative surface area is, at least initially, of a convex profile relative to membrane **32c** of conduit **28c**. Conduit **28c** comprises membrane **32c** and rigid wall **30c**. In this case, as compressible elastomeric material **36c** deforms and compresses to facilitate freeze protection in fluid passage **34c** defined by conduit **28c**, the operative surface, at first, becomes smaller. As freeze expansion continues, the operative surface area of the compressible elastomeric material **36c** eventually adopts a concave profile (see Figure 8). At this point, as freeze expansion continues, the operative surface area proceeds to become incrementally larger. In this case, the operative surface area of the compressible elastomeric material **36c** could be greater when compressible elastomeric material **36c** is either (i) in an uncompressed or pre-compressed state, or (ii) a compressed state. This would depend on the relative geometries of the fluid passage **34c**, membrane **32c**, compressible elastomeric material **36c**, and structural

support member **38c**. To minimize risk of failure of membrane **32c** due to tensile forces, therefore, the surface area of the membrane **32c** should exceed such greater value of the operative surface area.

Referring to Figure 3, in another embodiment of the present invention, support member **38a** may include perforations **39** for permitting evaporation of aqueous liquid which may permeate through membrane **32a** and become entrapped in compressible elastomeric material **36a**. Permeation of aqueous liquid is of particular concern where membrane **32a** is of a plastic material and therefore more likely to permit ingress of aqueous liquid from fluid passage **32a** into compressible elastomeric material **36a**. Failure to facilitate removal of the aqueous liquid from the compressible elastomeric material **36a** could compromise freeze protection efficacy of the present invention. As a necessary incident of this, it is preferable for the compressible elastomeric material **36a** to be of an open cell construction to facilitate diffusion of the aqueous liquid.

Figure 9 illustrates a further embodiment of the present invention, where rigid structural support member **44c** also include perforations **49** for external drainage of liquid trapped in compressible elastomeric material **46c**. The difference between the embodiment illustrated in Figure 3 and that which is illustrated in Figure 9 is the fact that the fluid conduit **40c** of the embodiment in Figure 9 is completely defined by a flexible membrane **48c**.

It is understood that the use of perforated or liquid permeable support members is not limited to the embodiments illustrated in Figures 3 and 9, and could be used in other variations of the present invention wherever support members are used to support compressible elastomeric material of the present invention, so long as the support member does not form part of the fluid containment structure, such variations including the embodiments depicted in Figures 4, 5, 6, 7 and 8.

Figures 10 - 14 are illustrative of a method of constructing an embodiment of the present invention having a rigid structural support member **110** comprising a seam **112** and a lock **114**. Rigid structural support member **110** is formed from a single thin metal sheet **116**, preferably of copper or aluminum. Sheet **116** comprises a first edge **126a** and a second edge **126b**, the first and second edges **126a** and **126b** being connected by a width **134**. A preferred thickness of sheet is 0.005 inches to 0.012 inches to provide for a desired combination of strength, heat transfer, manufacturability, and material cost features. Rigid structural member **110** supports compressible elastomeric material **118**. Each of rigid structural support member **110** and compressible elastomeric material **118** supports flexible fluid conduit **120**. Conduit **120** is comprised of flexible membrane **122**, and defines fluid passage **124**.

Referring to Figures 11 - 13, as a first step, first edge **126a** of sheet **116** is bent into a hem **128**, thereby forming a flap **130** (see Figure 11) then rolled over itself and forming an interior rolled-over surface portion **132**, thereby substantially defining the perimeter of rigid structural support member **110** (see Figure 12). The remaining width **134** of sheet extending from second edge is available to produce a first bend **136** and a second bend **138** (see Figure 13). First bend **136** joins a first portion **137a** of width **134** to a second portion **137b** of width **134**, the first portion **137a** and the second portion **137b** extending from first bend **136**. First bend **136** and second bend **138** are provided for engaging flap **130**, thereby forming lock **114**. Before engaging flap **130** with first and second bends **136** and **138**, flexible conduit **120** and compressible elastomeric material **118** are inlaid against interior rolled-over surface portion **132** (see Figure 13). Once flexible conduit **120** and compressible elastomeric material **118** are disposed in this manner, flap **130** is pressed into first bend **136**, between first portion **137a** and second portion **137b**, and then hem **128** is pressed against a point **129** on a surface of width **134** of sheet **116** to form seam **112** (see Figure 14). Second bend **138** is then pressed against flap **130**, thereby forming lock **114** (see Figure 10). Lock **114** enables the rigid structural support member **110** to resist internal fluid pressure that is transmitted through flexible conduit **120** and compressible elastomeric material **118**. Preferably, once the flap **130** is locked in place, hem **128** is rolled over itself a full 360 degrees.

It is understood that formation of bends **136** and **138** can occur before the rolling of first edge **126a** over itself, or even before formation of hem **128** and flap **130**. Further, it is understood that flexible conduit **120** and compressible elastomeric material **118** can be inlaid against interior rolled-over surface portion **132** immediately after rolling of first edge and before formation of bends **136** and **138**.

In one embodiment, any available sheet material width **134** extending between the second bend **138** and the second edge **126b** could be used to form an absorber plate in a solar thermal collector. In this respect, second bend **138** joins third portion **139a** of width **134** and fourth portion **139b** of width **134**. The third and fourth portions **139a** and **139b** extend from second bend **138** in different directions. The fourth portion **139b** has an available surface for forming an absorber plate in a solar thermal collector.

In one embodiment, the seam **112** and lock **114** formed in rigid structural support member **110** do not provide 100% fluid containment of any moisture which may become trapped in compressible elastomeric material. Seam **112** and lock **114** are not fluid tight but are, rather, permeable, thereby permitting the compressible elastomeric material **118** to breathe and facilitating

external drainage of liquid which may ingress into compressible elastomeric material **118** from fluid conduit **120.** In other words, rigid structural support member **110** and compressible elastomeric material **118** do not form a closed system.

In one embodiment, and as illustrated in Figure 10, compressible elastomeric material **118** is disposed between seam **112** and flexible conduit **120.** Positioning compressible elastomeric material **118** in this manner minimizes the risk of generating stress risers in flexible conduit **120** and further minimizes the risk of having flexible conduit **120** pry seam **112** open under the action of internal fluid pressure, which may eventually cause failure of lock **114** or flexible conduit **120.**

The above-described freeze protection means is not limited to straight lengths of conduits, as may be suggested by the embodiments illustrated in Figures 1 - 10. Because of the flexibility of the compressible elastomeric material and substantially liquid impermeable membrane, and particularly the unpressurized state of compressible elastomeric material, compressible elastomeric material and substantially liquid impermeable membrane can be readily adapted for use in bends, such as elbows or tees.

In one application, the present invention may be used within a fluid handling apparatus for absorbing heat in a solar thermal collector. Generally, depending on the climatic region, solar thermal collectors are exposed to cold temperature conditions. As a result, the working fluid, which is typically an aqueous liquid, circulating through the conduit, is susceptible to freezing and consequent expansion, thereby threatening the integrity of the walls of the conduit. Accordingly, solar thermal collectors would benefit from the freeze protection offered by the apparatus of the present invention.

Figure 15 illustrates a pictorial flowsheet of a typical solar thermal collector **50**, used on the roof **52** (or facade) of a typical building structure, comprising an array of individual collectors **56**, absorber units **58** associated with each collector **56**, and a storage vessel **60** for containing working fluid which is circulated through collector **50**. Motive means **62**, such as a pump, are provided to recirculate working fluid from storage vessel **60**, through collector **50**, and back to storage vessel **60**. Motive means **62** draws working fluid from storage vessel **60** and introduces working fluid to collector **50** via supply line **64**. Supply line **64** is connected to the supply manifold **66** of collector **50** for distribution to individual absorber units **58**. Supply manifold **66** supplies working fluid to absorber units **58** by connection to supply header **68** of an absorber unit **58**. Working fluid is conducted through each absorber unit **58** through a plurality of closely spaced elongated piping **70** which are connected to supply header **68**, and discharge into discharge header **72**. Discharge header

**72** may be connected to supply header **68** of another absorber unit **58** or may directly discharge to return manifold **74** for return to storage vessel **60** via return line **76**.

Alternatively, aqueous fluid may be conducted through solar thermal collector **50** by a single conduit. In this respect, conduit would be connected at one end to supply line **64**, and to return line **76** at the other end. Within each absorber unit **58**, conduit would adopt a generally serpentine geometry as a mean of enhancing heat transfer efficiencies.

Referring to Figures 15 and 16, working fluid which travels through piping **70** in any of the absorber units **58** are in contact with absorber sheet **78**. Absorber sheet **78** is exposed to and absorbs incident solar radiation, thereafter converting such radiation to heat and conducting such heat to the working fluid circulating within piping **70**. Heated aqueous liquid is discharged into return line **76** to be returned to storage vessel **60**. Heated water in storage vessel **60** may be subsequently used as a source of domestic hot water supply or as a heat source for various applications, such as for space heating or pool heating, or could be used in commercial applications and industrial processes.

Every fluid passage in solar thermal collector **50** may be adapted for use with the freeze protection apparatus of the present invention. Referring to Figures 15 and 16, a section of a typical fluid passage **80** is shown adapted for use with the freeze protection apparatus of the present invention by defining such fluid passage **80** with flexible conduit **82** wherein flexible conduit **82** is disposed within rigid structural support member **84**. Also disposed within rigid structural support member **84** is compressible elastomeric material **88**.

Rigid structural support member **84** comprises absorber sheet **78** and undercarriage **90**. Absorber sheet **78** is connected to undercarriage **90** to cause containment of flexible conduit **82** and compressible elastomeric material **88**.

Flexible conduit **82** comprises a substantially liquid impermeable membrane **92**, which functions as a flexible wall for conduit **82**, and includes an upper wall **94** and a lower wall **96**. Upper wall **94** is disposed in substantially adjacent relationship with absorber sheet **78**, thereby receiving structural support from absorber sheet **78**. Additionally, such configuration facilitates conductance of heat from absorber sheet **78** to aqueous liquid in fluid passage **80** of conduit **82**. Lower wall **96** is disposed in substantially adjacent relationship with compressible elastomeric material **88**, thereby receiving structural support from compressible elastomeric material **88**.

For further illustration, Figure 17 shows a fluid passage **80a** within collector **50** (Figure 16) between adjoining first absorber unit **58a** and second absorber unit **58b**. Fluid passage **80a** connects discharge header **72** of first absorber unit **58a** with supply header **68** of second absorber unit **58b**.

As any typical fluid passage **80** (Figure 16) in collector unit **50**, fluid passage **80a** is defined by flexible conduit **82**, disposed within rigid structural support member **84**. Also disposed within rigid structural support member **84** is compressible elastomeric material **88**. In this respect, flexible conduit **82** is supported by rigid structural support member **84** and compressible elastomeric material **88**.

Fluid passages between the collector unit **50** and supply line **64** (Figure 15), including supply manifold **66**, and within supply line **64**, may be exposed to cold temperature conditions to some extent. The same is true with respect to fluid passages between collector unit **50** and return line **76**, including return manifold **74**, and within return line **76**. In this respect, where such fluid passages are exposed to cold temperature conditions, the corresponding conduit is protected from freeze damage by the present invention.

Figures 18, 19 and 20 illustrate a typical fluid passage **90** between exterior to collector **50**, and is representative of the connection of collector **50** to supply line **64**, or the connection of collector **50** to return line **76**. Flexible conduit **92** is provided to define fluid passage **90** where fluid passage **90** may be exposed to cold temperature conditions. Accordingly, with respect to the solar thermal collector system in Figure 6, flexible conduit **92** is provided in fluid passages connecting supply header of absorber unit **58a** to supply manifold, and extend into supply line **64** where freeze damage is a concern. Similarly, flexible conduit **92** is provided in fluid passages connecting discharge header of absorber unit **58c** to return manifold, and extend into return line **76** where freeze damage is a concern.

Flexible conduit **92** comprises a substantially liquid impermeable membrane **94** and is disposed within rigid structural support member **96**. Also, disposed within rigid structural support member **96** is compressible elastomeric material **98**. In this respect, flexible conduit **92** is supported by rigid structural support member **96** and compressible elastomeric material **98**.

Where freeze damage is no longer a concern, with respect to supply line **64** or return line **76**, supply line **64** or return line **76** comprises a rigid conduit **100**. Rigid conduit **100** is connected in fluid tight manner with flexible conduit **92** at a location where freeze damage is not a concern. Beyond this point, freeze protection apparatus of the present invention is no longer required. In this respect, referring particularly to Figures 18, 19 and 20, compressible elastomeric material **98** will terminate longitudinally at end plate **102** which forms part of rigid structural support member **96**.

While one application of the present invention has been described with respect to solar thermal collection **50**, it should be readily understood that the present invention is equally applicable

to a liquid containing conduit or other apparatus which is subject to freezing in heat transfer and non-heat transfer processes. As a further example of its application to a heat transfer process, the present invention may be used as a means of absorbing heat from a photovoltaic cell.

It will be understood, of course, that modifications can be made in the embodiments of the invention illustrated and described herein without departing from the scope and purview of the invention as defined by the appended claims.

We claim,

1. An elongated conduit for conveying or containing aqueous liquid, defining a liquid passage, comprising a first portion and a second portion, the first portion being a rigid wall and the second portion being a substantially liquid impermeable flexible membrane, wherein said membrane is disposed in substantially adjacent relationship with a compressible elastomeric material, said compressible elastomeric material being supported by a rigid support member, said rigid support member being liquid permeable.

2. The conduit of claim 1, wherein said rigid support member comprises perforations for facilitating external drainage of liquid.

3. The conduit of claim 1, wherein said conduit forms part of a solar thermal collector.

4. The conduit of claim 1, wherein said compressible elastomeric material is selected from the group consisting of foamed butyl rubber, foamed neoprene, silicone foam, silicone sponge rubber, foamed EPDM, and urethane foam.

5. An elongated conduit for conveying or containing aqueous liquid, defining a liquid passage, comprising a first portion and a second portion, the first portion being a rigid wall and the second portion being a substantially liquid impermeable flexible membrane, said rigid wall being attached to said flexible membrane wherein together they form an outer perimeter of said liquid passage, wherein said membrane is disposed in substantially adjacent relationship with a compressible elastomeric material, wherein said membrane has a first surface characterized by a first surface area, and said compressible elastomeric material has a second surface characterized by a second surface area, said first surface being in substantially adjacent relationship with said second surface, said first surface area exceeding the greater of:

(i) said second surface area, when said liquid passage contains no liquid and said compressible elastomeric material is:

a) in an uncompressed state, or

b) in a precompressed state, and

(ii) said second surface area when said compressible elastomeric material is in its compressed state as a result of freeze expansion of said aqueous liquid.

6. The conduit of claim 5 wherein said conduit forms part of a solar thermal collector.

7. The conduit of claim 5, wherein said compressible elastomeric material is selected from the group consisting of foamed butyl rubber, foamed neoprene, silicone foam, silicone sponge rubber and urethane foam.

8. A conduit for conveying or containing aqueous liquids, comprising a substantially liquid impermeable flexible membrane for defining a liquid passage, wherein said membrane is disposed in substantially adjacent relationship with a compressible elastomeric material, said compressible elastomeric material being supported by a rigid support member, said rigid support member being liquid permeable.

9. The conduit of claim 8, wherein said rigid support member comprises perforations for facilitating external drainage of liquid.

10. The conduit of claim 8, wherein said conduit forms part of a solar thermal collector.

11. The conduit of claim 8, wherein said compressible elastomeric material is selected from the group consisting of foamed butyl rubber, foamed neoprene, silicone foam, silicone sponge rubber and urethane foam.

12. The conduit of claim 8 wherein said membrane has a first surface characterized by a first surface area, and said compressible elastomeric material has a second surface characterized by a second surface area, said first surface being in substantially adjacent relationship with said second surface, said first surface area exceeding the greater of:

(i) said second surface area, when said liquid passage contains no liquid and said compressible elastomeric material is:

   a) in an uncompressed state, or

   b) in a precompressed state, and

(ii) said second surface area when said compressible elastomeric material is in its compressed state as a result of freeze expansion of said aqueous liquid.

13. A conduit for conveying or containing aqueous liquids, comprising a substantially liquid impermeable flexible membrane for defining a liquid passage, wherein said membrane is disposed in substantially adjacent relationship with a compressible elastomeric material, and wherein said membrane has a first surface characterized by a first surface area, and said compressible elastomeric material has a second surface characterized by a second surface area, said first surface being in substantially adjacent relationship with said second surface, said first surface area exceeding the greater of:

(i) said second surface area, when said liquid passage contains no liquid and said compressible elastomeric material is:

a) in an uncompressed state, or

b) in a precompressed state, and

(ii) said second surface area when said compressible elastomeric material is in its compressed state as a result of freeze expansion of said aqueous liquid.

14. The conduit of claim 13, wherein said conduit forms part of a solar thermal collector.

15. The conduit of claim 13, wherein said compressible elastomeric material is selected from the group consisting of foamed butyl rubber, foamed neoprene, silicone foam, silicone sponge rubber and urethane foam.

16. A conduit for conveying or containing aqueous liquids comprising a substantially liquid impermeable flexible membrane for defining a liquid passage, said membrane being disposed in substantially adjacent relationship with a compressible elastomeric material, said membrane including a first portion and a second portion wherein an exterior of said first portion is disposed in substantially adjacent relationship with a first rigid structural support member and an exterior of said second portion is disposed in substantially adjacent relationship with a compressible elastomeric material.

17. The conduit of claim 16, wherein said conduit forms part of a solar thermal collector.

18. The conduit of claim 16, wherein said compressible elastomeric material is selected from the group consisting of foamed butyl rubber, foamed neoprene, silicone foam, silicone sponge rubber and urethane foam.

19. The conduit of claim 16, wherein said compressible elastomeric material is supported by a second rigid structural support member and said member is liquid permeable for external drainage of aqueous liquid.

20. The conduit of claim 16, wherein said membrane has a first surface characterized by a first surface area, and said compressible elastomeric material has a second surface characterized by a second surface area, said first surface being in substantially adjacent relationship with said second surface, said first surface area exceeding the greater of:

(i) said second surface area, when said liquid passage contains no liquid and said compressible elastomeric material is:

a) in an uncompressed state, or

b) in a precompressed state, and

(ii) said second surface area when said compressible elastomeric material is in its compressed state as a result of freeze expansion of said aqueous liquid.

21. A conduit for conveying or containing aqueous liquids comprising a substantially liquid impermeable flexible membrane for defining a liquid passage, said membrane being disposed in substantially adjacent relationship with a compressible elastomeric material, said membrane and said compressible elastomeric material supported by a rigid support member wherein said rigid support member is formed from a single sheet having a first edge and a second edge joined by a width, said single sheet being bent proximate said first edge to form a hem and a flap, said first edge being rolled over itself to form an interior rolled-over surface portion, said single sheet further provided with a first bend along said width, said membrane and said compressible elastomeric material being substantially contained by said interior rolled-over surface portion, said first bend being disposed between said hem and said second edge, said flap being disposed within said first bend to form a lock.

22. The conduit of claim 21, wherein said first bend joins a first portion of said width to a second portion of said width, said first portion and said second portion extending from said first bend, said flap being inserted and pressed between said first portion and said second portion whereby said flap lockingly engages said first bend.

23. The conduit of claim 22, wherein said lock is liquid permeable.

24. The conduit of claim 23, wherein said hem contacts a surface of said width to form a seam.

25. The conduit of claim 24, wherein said compressible elastomeric material is disposed between said seam and said membrane.

26. The conduit of claim 25, wherein said seam is liquid permeable.

27. The conduit of claim 21, wherein said single sheet is further provided with a second bend disposed between said first bend and said second edge, said second bend joining a third portion of said width to a fourth portion of said width, said third portion and said fourth portion extending from said second bend, said fourth portion forming an absorber plate in a solar thermal collector.

28. A method of constructing a freeze protected conduit for conveying or containing aqueous liquids comprising the steps of:

(i) bending a single sheet having a first edge and a second edge joined by a width to form a hem and a flap proximate said first edge;

(ii) rolling said first edge over itself to form an interior rolled-over surface portion;

(iii) bending said sheet at a first point along said width between said hem and said second edge to form a first bend, said first bend joining a first width portion and a second width portion, said first width portion and said second width portion extending from said first bend;

(iv) inlaying a flexible conduit and compressible elastomeric material against said interior rolled-over surface portion for effecting containment and support of said flexible conduit and said elastomeric material; and

(v) pressing said flap between said first width portion and said second width portion to form a lock.

29. The method of claim 28, wherein step (iv) must occur before step (v) and after step (ii), and wherein step (iii) must occur before step (v).

30. The method of claim 28, wherein said hem contacts a second point along said width of said sheet during step (ii).

31. A freeze protected conduit for conveying or containing aqueous liquids, defining a liquid passage, comprising a substantially liquid impermeable membrane disposed in substantially adjacent relationship with a compressible elastomeric material, wherein said membrane comprises silicone rubber.

32. The conduit of claim 31, wherein said membrane has a thickness within the range of about 0.007 inches to about 0.020 inches.

33. The conduit of claim 31, wherein said conduit is used in heat transfer applications.

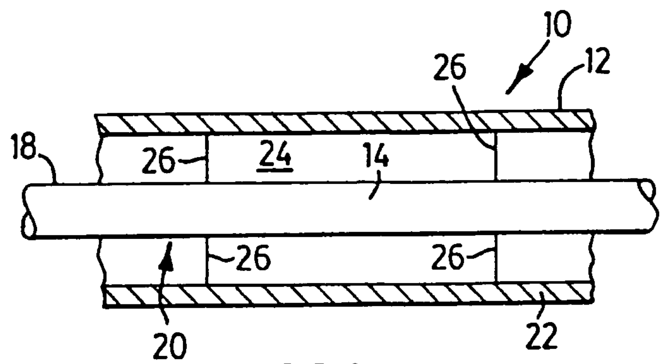



FIG. 1

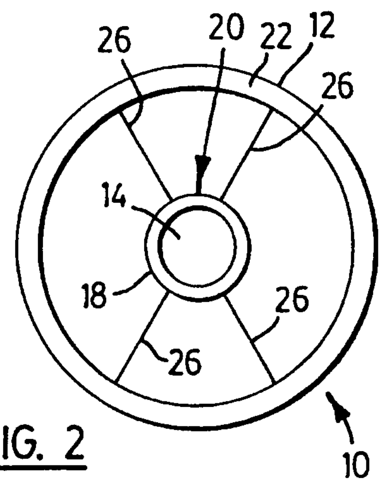



FIG. 2

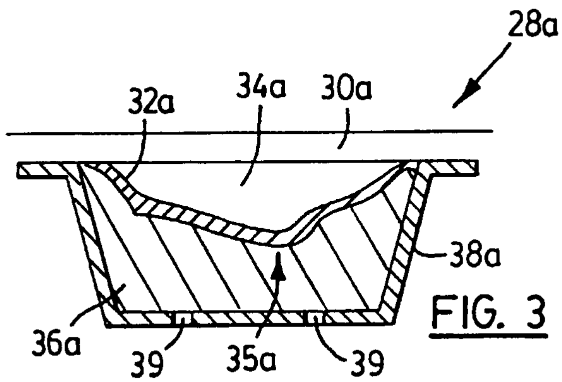



FIG. 3

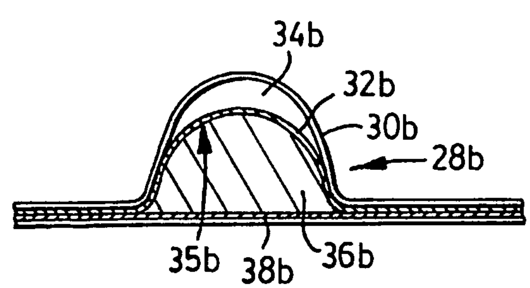



FIG. 4

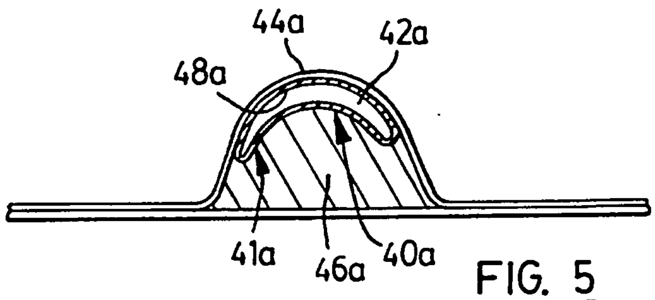



FIG. 5

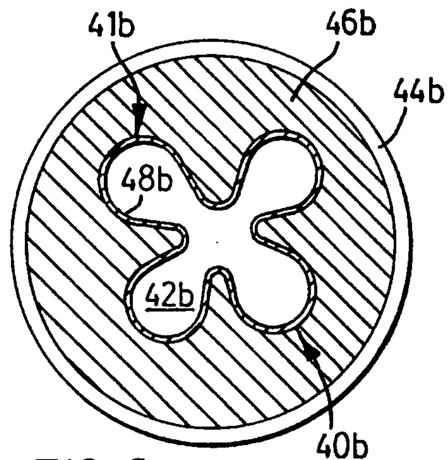



FIG. 6

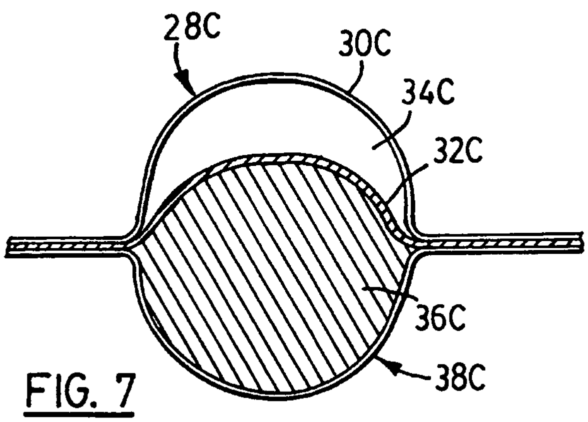



FIG. 7

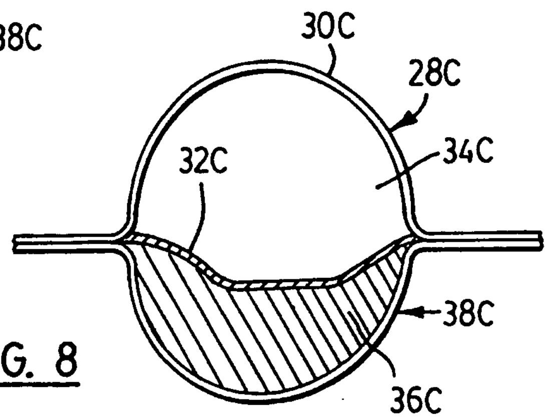



FIG. 8

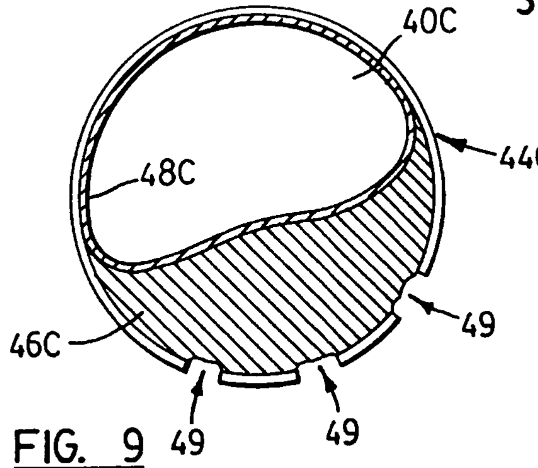



FIG. 9

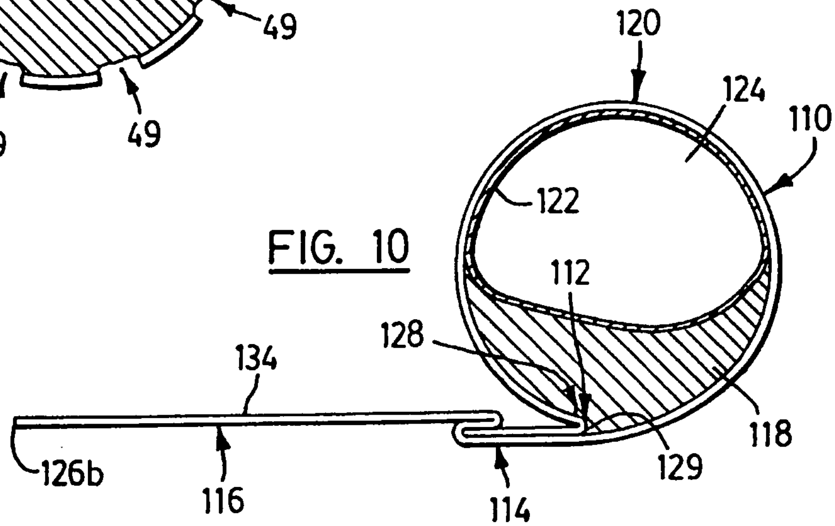



FIG. 10

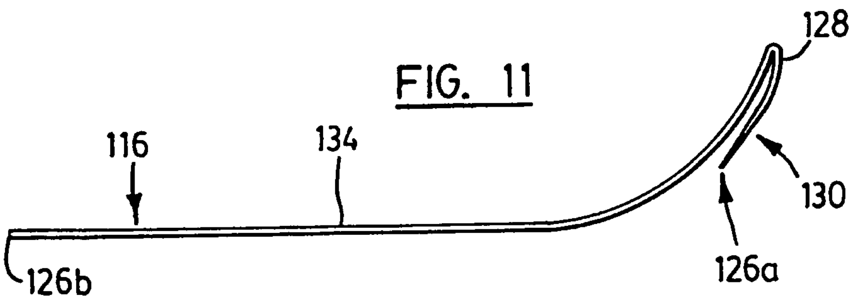



FIG. 11

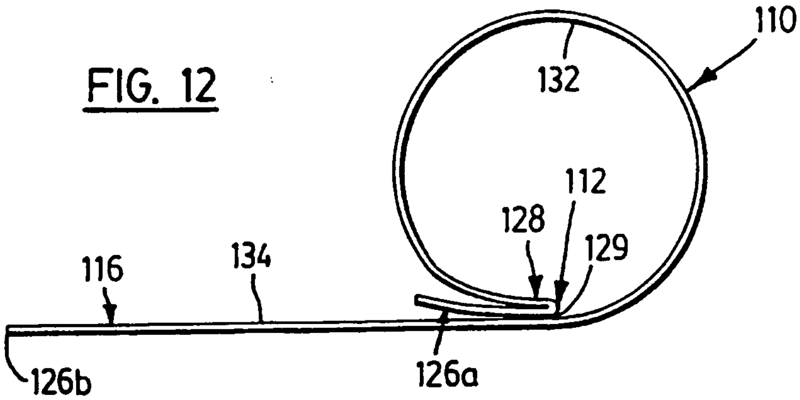



FIG. 12

FIG. 13

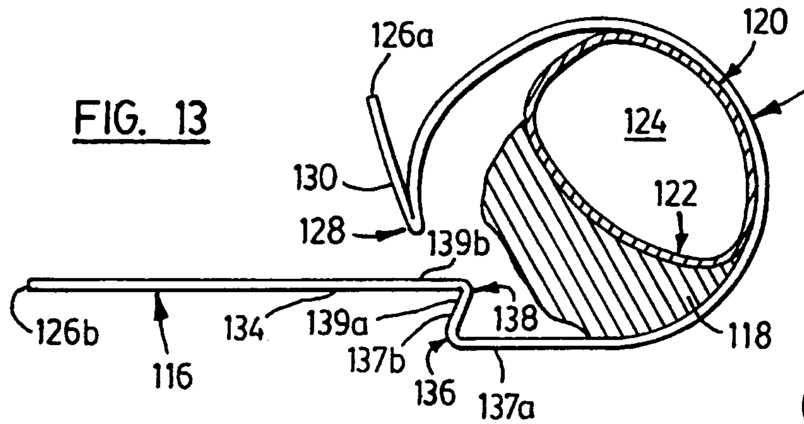
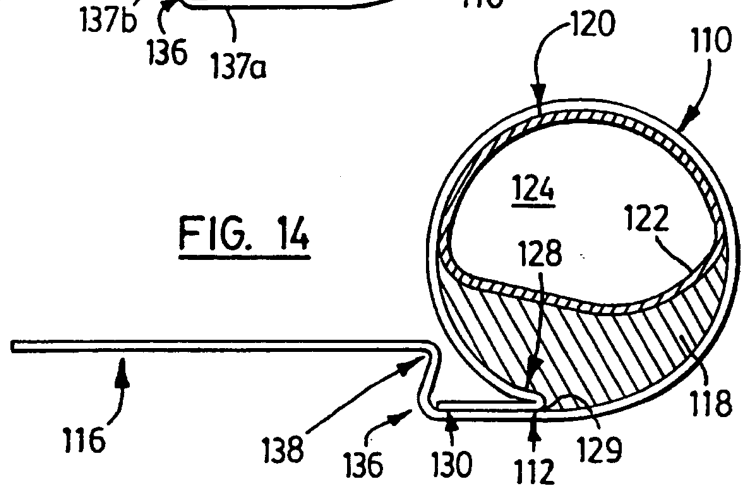



FIG. 14



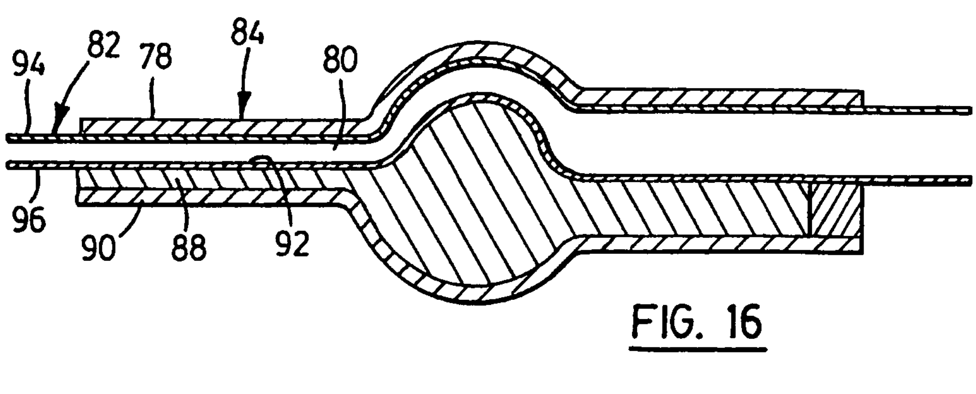




FIG. 16

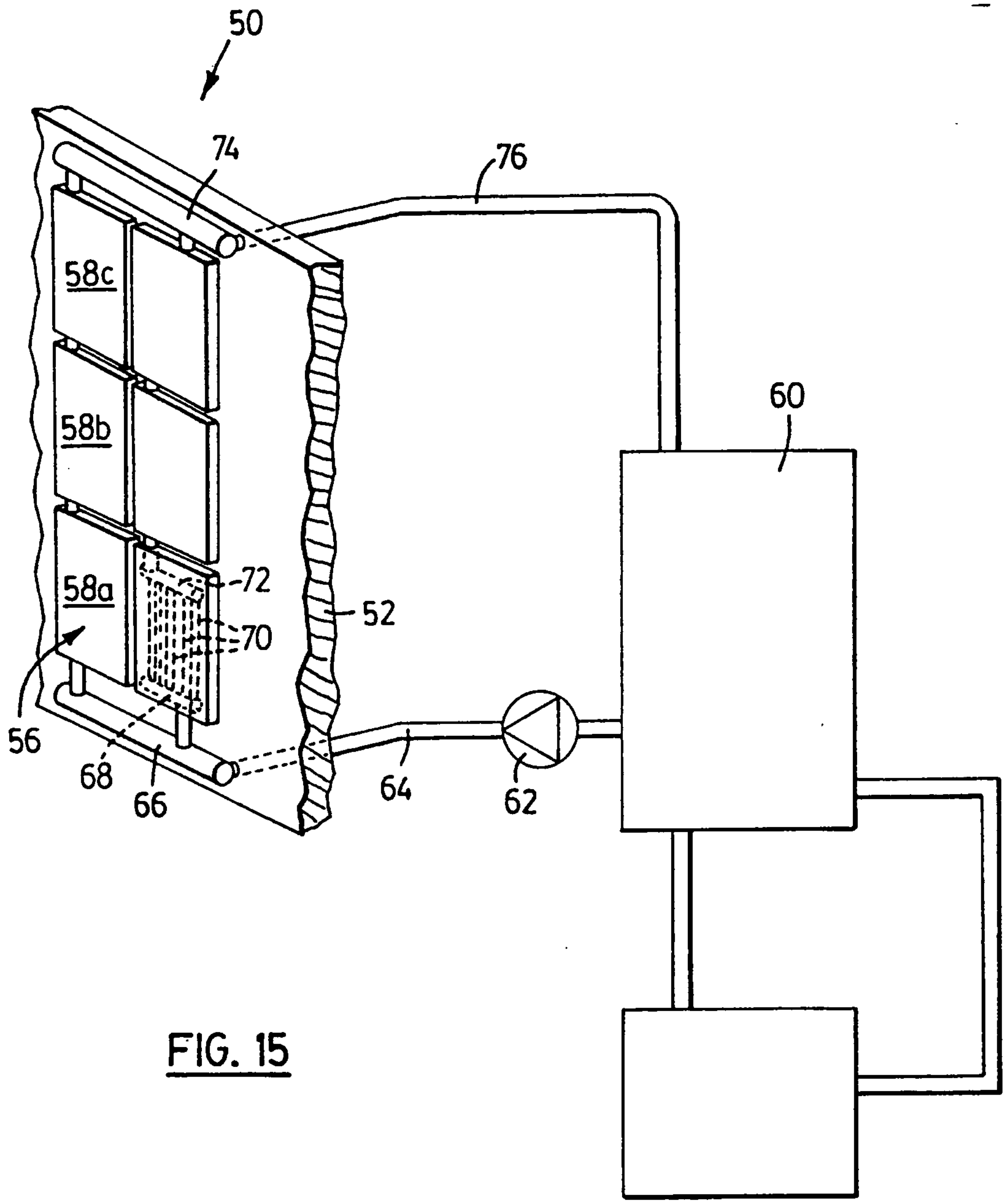



FIG. 15

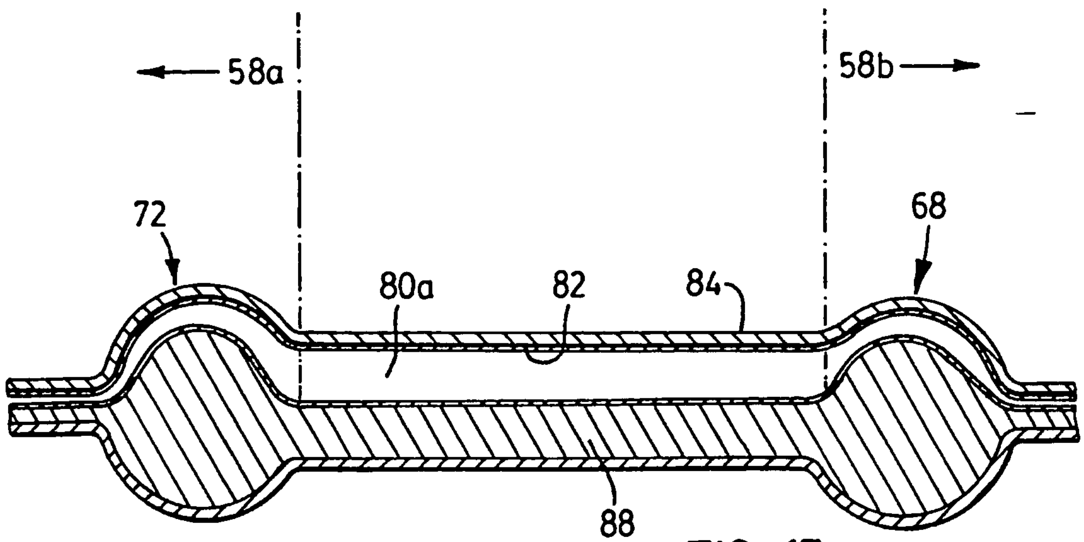

58a
58b
72
68
80a
82
84
88

FIG. 17

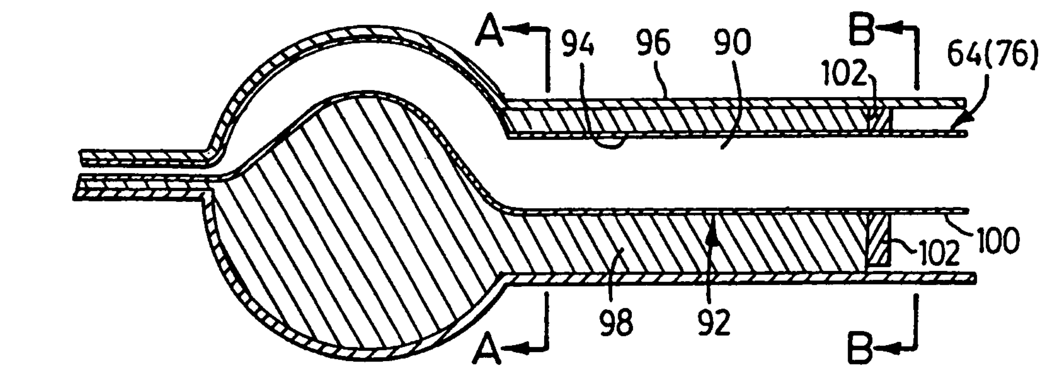

TO ABSORBER 58a(58c)
IN COLLECTOR 50
A
94
96
90
B
102
64(76)
100
102
98
92
A
B

FIG. 18

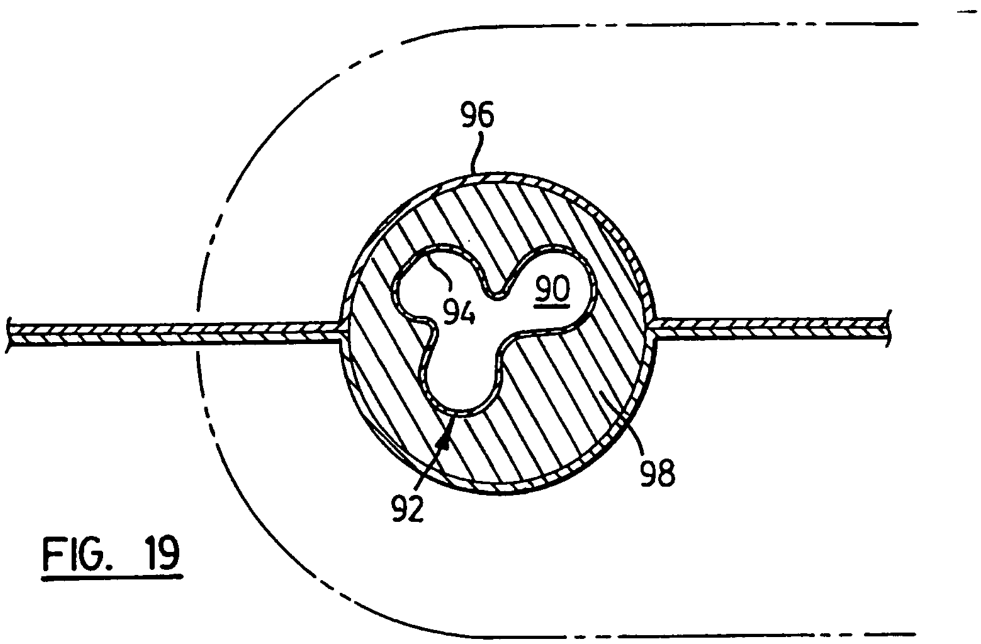



FIG. 19

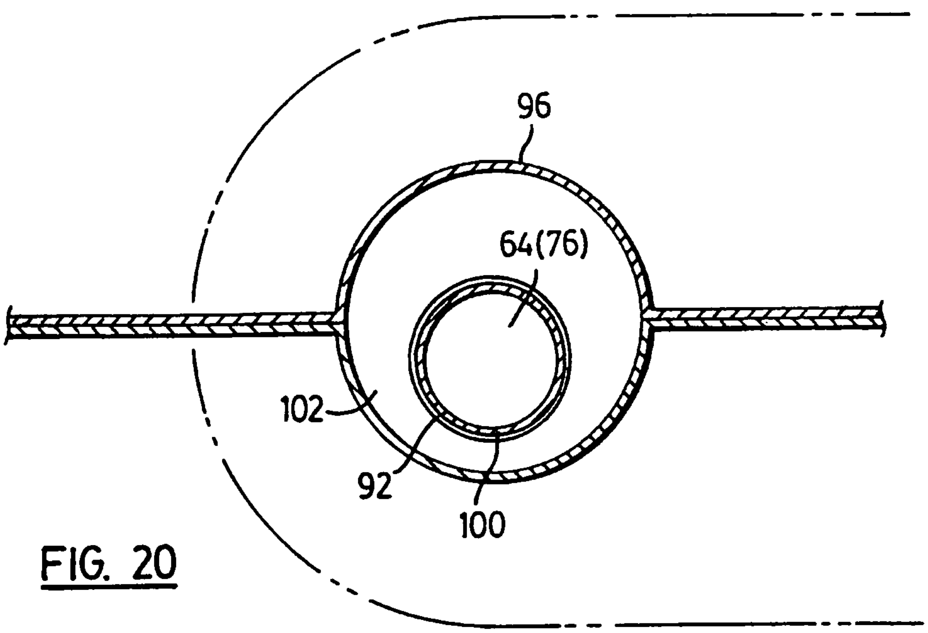



FIG. 20

# INTERNATIONAL SEARCH REPORT

International Application No
PCT/CA 99/00824

**A. CLASSIFICATION OF SUBJECT MATTER**
IPC 7 F24J2/46 E03B7/10

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 F24J E03B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | FR 2 478 161 A (FABRE JEAN) 18 September 1981 (1981-09-18) | 16-18, 31,33 |
| A | page 4, line 3 - line 4<br>page 4, line 30 -page 5, line 20<br>page 7, line 1 - line 8; figures | 1-15 |
| X | GB 2 167 827 A (RICHMOND JOHN HENRY) 4 June 1986 (1986-06-04) | 16,31 |
| A | page 1, line 33 -page 2, line 14<br>page 2, line 24 - line 29; figures; tables | 1-20,32 |
| X | US 1 927 105 A (SOLOMON J. WELCH) 19 September 1933 (1933-09-19)<br>the whole document | 31 |
| A | CH 512 043 A (ABIG GMBH) 31 August 1971 (1971-08-31)<br>the whole document | 1-20, 31-33 |

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 19 November 1999 | 30/11/1999 |

| Name and mailing address of the ISA | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,<br>Fax: (+31-70) 340-3016 | MOOTZ, F |

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